# Second Generation PFBC
# Systems R&D - Phase 2 and Phase 3

## YEARLY TECHNICAL REPORT

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# PRESSURIZED FLUIDIZED BED COMBUSTION

# SECOND-GENERATION SYSTEM RESEARCH AND DEVELOPMENT

TECHNICAL PROGRESS FOR PHASE 2
OCTOBER 1, 1998 THROUGH SEPTEMBER 1999


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October 1999

Work Performed Under Contract: DE-AC21-86MC21023

For:

U.S. Department of Energy
Office of Fossil Energy
Federal Energy Technology Center
Morgantown, West Virginia

By:

Foster Wheeler Development Corporation
Livingston, New Jersey

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**FOR OCTOBER 1, 1998 THROUGH SEPTEMBER 1999**

When DOE funds were exhausted in March 1995, all Phase 2 activities were placed on hold. In February 1996 a detailed cost estimate was submitted to the DOE for completing the two remaining Phase 2 Multi Annular Swirl Burner (MASB) topping combustor test campaigns; in August 1996 release was received from FETC to proceed with the two campaigns to:

1. test the MASB at proposed demonstration plant full to minimum load operating conditions

2. identify the lower oxygen limit of the MASB

3. demonstrate natural gas to carbonizer fuel gas switching.

4. demonstrate operation with “low temperature” compressor discharge air rather than high temperature (.1600EF) vitiated air.

The 18 in. MASB was last tested at the University of Tennessee Space Institute (UTSI) in a high-oxygen configuration and must be redesigned/modified for low oxygen operation. A second-generation PFB combustion plant incorporating an MASB based topping combustor has been proposed for construction at the City of Lakeland’s McIntosh Power Plant under the U.S. DOE Clean Coal V Demonstration Plant Program. This plant will require the MASB to operate at oxygen levels that are lower than those previously tested. Preliminary calculations aimed at defining the operating envelope of the demonstration plant MASB have been completed.

The previous MASB tests have been performed at UTSI in a facility constructed to support the development of MHD power generation. Because of a loss of MHD funding, the UTSI facility closed October 1998. On February 2, 1999, Siemens Westinghouse proposed a 12-week study that would identify the cost of modifying the MASB for Lakeland low oxygen operation conditions and conducting tests 3 and 4 above at the Arnold Engineering Development Center (AEDC). On February 22, 1999, Siemens Westinghouse was given release to proceed with this study and results/recommendations were received on April 22, 1999. Siemens Westinghouse recommended a two-phase test effort.

The first test effort would entail two 6-hour tests beginning November 1999 with the MASB operated with natural gas and “cold” compressor air. The MASB would be tested at full Lakeland pressure using the physical configuration planned for operation at lower pressure at Wilsonville in September 1999. As a result, the MASB test specimen would be a totally new unit (not a modification of a previously UTSI tested unit). The MASB would be installed in an existing AEDC test shell as shown in Fig. 1. Although the internals currently installed within the shell would have to be removed and reinstalled at the completion of the first test phase, no major facility modifications external to the shell are needed; this first test effort was estimated to cost $1.2 million.

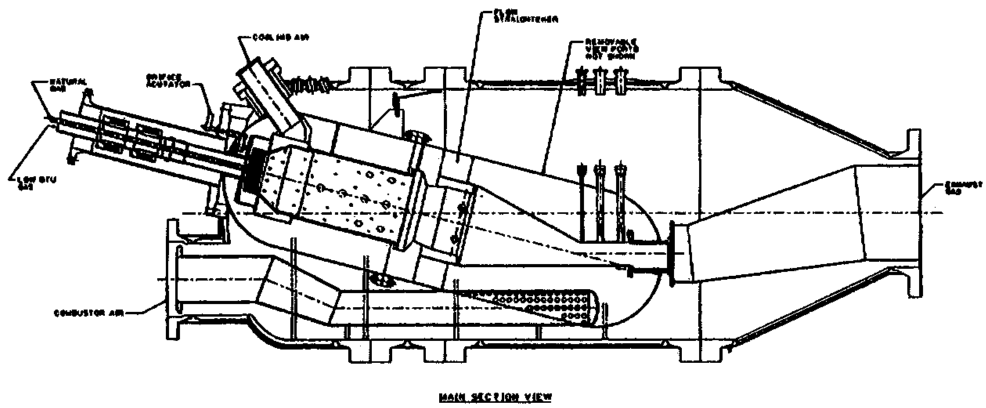


Figure 1  MASB in AEDC Test Rig

Although the second test effort was not the subject of this initial study, Siemens Westinghouse envisioned it being conducted in another AEDC test cell that is currently mothballed.  The facility has been well preserved and it would be modified to permit syngas testing with both cold and hot vitiated air; these tests would not be conducted until the fall 2000 and were estimated to cost $3.2 million.

Written questions were submitted to Siemens Westinghouse regarding their proposed test programs; their responses and cost estimates were transmitted to FETC on April 30, 1999.

Review of the proposed programs by FETC revealed that they exceeded existing funding limits, and all further Phase 2 work was put on hold until additional funding becomes available.

# PRESSURIZED FLUIDIZED BED COMBUSTION

## SECOND-GENERATION SYSTEM RESEARCH AND DEVELOPMENT

TECHNICAL PROGRESS FOR PHASE 3
OCTOBER 1, 1998 THROUGH SEPTEMBER 1999


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## Commercial Plant Design Update

The Second-Generation PFB Combustion Plant conceptual design prepared in 1987 is being updated to reflect the benefit of pilot plant test data and the latest advances in gas turbine technology. The updated plant is being designed to operate with 95 percent sulfur capture and a single Siemens Westinghouse (SW) 501G gas turbine. Our 1987 study investigated two coal feeding arrangements, e.g., dry and paste feed. Paste feeding resulted in a lower cost of electricity. Paste, however, increases the water content of the carbonizer generated syn gas; this increases the equilibrium partial pressure of hydrogen sulfide gas over calcium oxide/calcium carbonate and thereby reduces the carbonizer sulfur capture efficiency. Recognizing that the carbonizer and the CPFBC work together to control the plant overall sulfur capture efficiency, the higher CPFBC efficiency can compensate for the carbonizer's lower sulfur capture efficiency depending upon the amount of coal and/or char being fed to each unit. Since the latter are determined by the overall plant heat and material balance, we prepared a carbonizer balance (see Fig. 1 and 2) for each feed case to enable selection of the plant coal feed system.

Siemens Westinghouse 501G gas turbine performance estimates were received for both the dry feed and paste feed cases. Following several iterations that were conducted with SW to iron out discrepancies in the turbine performance data, Parsons completed "first cut" plant heat and material balances for both the dry feed and paste feed cases that yielded the following:

| | Dry Feed | Paste Feed |
|---|---|---|
| Gas Turbine Power, MWe | 231.17 | 244.28 |
| Steam Turbine Power, MWe | 208.55 | 194.68 |
| Gross Power, MWe | 439.72 | 438.96 |
| Auxiliary Load (5%), MWe | 21.99 | 21.95 |
| Net Power Output, MWe | 417.73 | 417.01 |
| % Efficiency (HHV) | 45.2 | 41.3 |

The dry feed plant thermal efficiency is much greater than the paste feed. There are two fundamental reasons for this: (1) the dry feed case gas turbine simple cycle efficiency is 1.1% greater than the paste feed case, and, (2) the dry feed case generates proportionally less LP steam thereby making more efficient use of the rejected heat.

**Product Gas**

| | Lb/hr | Mol% |
|---|---|---|
| CO | 51.793 | 16.708 |
| CO2 | 43.960 | 9.026 |
| H2 | 3.307 | 14.823 |
| H2O | 19.692 | 9.877 |
| CH4 | 3.198 | 1.801 |
| NH3 | .417 | .221 |
| H2S | .114 | .030 |
| N2 | 145.521 | 46.940 |
| Ar | 2.529 | .572 |
| Sum | 270.532 | 100.000 |

HHV(Btu/Lb)= 1867.
LHV(Btu/Lb)= 1723.
HHV(Btu/scf)= 127.
LHV(Btu/scf)= 118.

**Char-Sorbent**

| | Lb/hr | | Lb/hr |
|---|---|---|---|
| C | 21.578 | CaCO3 | 7.136 |
| H | .136 | MgCO3 | .000 |
| O | .000 | CaO | .000 |
| N | .377 | MgO | 4.857 |
| S | .432 | CaS | 4.036 |
| Ash | 8.033 | Inert | .398 |
| Sum | 30.557 | Sum | 16.427 |

HHV(Btu/Lb Char)=10603.
LHV(Btu/Lb Char)=10563.

HHV(Btu/Lb Sorb)= 1085.
(on CaCO3-MgCO3 base)

QPFB(LHV:Btu/Lb Avg)= 7292.

**CARBONIZER**

P(psia)=294.
T(F)=1700.

Purge ---------->  77.F

| | Lb/hr |
|---|---|
| N2 | .000 |

Steam <--------  415.F

| | Lb/hr |
|---|---|
| | .000 |

Coal 70.F

| | Lb/hr |
|---|---|
| C | 56.060 |
| H | 3.656 |
| O | 4.940 |
| N | .980 |
| S | 2.333 |
| Ash | 8.033 |
| Moist | 24.000 |
| Sum | 100.003 |

HHV(Btu/Lb MF)=13250.

Sorbent 70.F

| | Lb/hr |
|---|---|
| CaCO3 | 12.735 |
| MgCO3 | 10.160 |
| Moist | .117 |
| Inert | .398 |
| Sum | 23.410 |

Ca/S= 1.750

Air 600.F

| | Lb/hr |
|---|---|
| O2 | 44.736 |
| N2 | 145.261 |
| Ar | 2.529 |
| H2O | 1.577 |
| CO2 | .000 |
| Sum | 194.103 |

Stoi% 25.399

Note: HHV & LHV - Fuel heating value as it burns out @ STD.

Phase 3 Paste Feed 1700EF Carbonizer Balance 6/4/98

Figure 1

**Product Gas**

| | Lb/hr | Mol% |
|---|---|---|
| CO | 63.127 | 19.848 |
| CO2 | 36.759 | 7.356 |
| H2 | 3.868 | 16.898 |
| H2O | 15.802 | 7.725 |
| CH4 | 4.102 | 2.252 |
| NH3 | .459 | .237 |
| H2S | .086 | .022 |
| N2 | 143.492 | 45.111 |
| Ar | 2.493 | .550 |
| Sum | 270.189 | 100.000 |

HHV(Btu/Lb)= 2260.
LHV(Btu/Lb)= 2088.
HHV(Btu/scf)= 150.
LHV(Btu/scf)= 139.

**Char-Sorbent**

| | Lb/hr | | Lb/hr |
|---|---|---|---|
| C | 34.428 | CaCO3 | 9.397 |
| H | .217 | MgCO3 | .000 |
| O | .000 | CaO | .000 |
| N | .602 | MgO | 6.231 |
| S | .689 | CaS | 5.001 |
| Ash | 10.306 | Inert | .510 |
| Sum | 46.242 | Sum | 21.140 |

HHV(Btu/Lb Char)=11179.
LHV(Btu/Lb Char)=11137.

HHV(Btu/Lb Sorb)= 1050.
(on CaCO3-MgCO3 base)

QPFB(LHV:Btu/Lb Avg)= 8016.

```
                  FWFWFWFWFWFWFWFWFWFW
        77.F      F                  W      415.F
Purge ---------->F     CARBONIZER    W <--------- Steam
                  F                  W
    Lb/hr         F    P(psia)=294.  W          Lb/hr
N2   .000         F    T(F)=1700.    W          16.180
                  F                  W
                  FWFWFWFWFWFWFWFWFWFW
        70.F/          70.F|        600.F\
   Coal                Sorbent              Air
```

**Coal**

| | Lb/hr |
|---|---|
| C | 71.912 |
| H | 4.690 |
| O | 6.337 |
| N | 1.258 |
| S | 2.993 |
| Ash | 10.306 |
| Moist | 2.500 |
| Sum | 99.996 |

HHV(Btu/Lb MF)=13250.

**Sorbent**

| | Lb/hr |
|---|---|
| CaCO3 | 16.336 |
| MgCO3 | 13.033 |
| Moist | .150 |
| Inert | .510 |
| Sum | 30.029 |

Ca/S= 1.750

**Air**

| | Lb/hr |
|---|---|
| O2 | 44.105 |
| N2 | 143.213 |
| Ar | 2.493 |
| H2O | 1.555 |
| CO2 | .000 |
| Sum | 191.367 |

Stoi% 19.521

Note: HHV & LHV - Fuel heating value as it burns out @ STD.

Phase 3 Dry Feed 1700EF Carbonizer Balnace 6/4/98

Figure 2

With paste feed yielding a significantly lower efficiency, it was decided to base the plant design on dry feed. Parsons reworked the steam cycle adding an additional extraction for a stand alone deaerator, split the boost air cooler into economizing and evaporative heat transfer zones, and increased the aggressiveness of the Spencer/Cotton/Cannon efficiency estimates. The result was a new system efficiency estimate of 46.4 percent HHV. The total gas flow through the gas turbine in the reworked plant is about 2% higher than that originally given to Siemens Westinghouse (SW). As a result, SW was asked to update their gas turbine power output.

All analyses conducted to date utilized a 1700EF carbonizer. Increasing the carbonizer temperature increases the conversion of coal to syngas energy resulting in less char energy for the steam cycle. Since reducing the size of the steam turbine relative to the gas turbine will increase the plant efficiency, analyses were begun to determine the effect of increasing the carbonizer temperature to 1800EF. Fig. 3 identifies the 1800EF carbonizer performance predicted by FW. Compared with 1700EF operation, the gas heating value is about 6½% lower, but the gas yield per pound of coal is about 17% higher resulting in about 30% less char energy. Using the Fig. 3 balance Parsons generated “first cut” balance data for this new carbonizer operating condition and forwarded it to SW for gas turbine performance predictions. As the reporting period ended, SW was completing its analyses of these two cases.

```
      Product Gas                                    Char-Sorbent

          Lb/hr       Mol%                        Lb/hr                 Lb/hr
CO     86.779       22.038              C      24.231     CaCO3      .000
CO2    43.031        6.955              H        .153     MgCO3      .000
H2      4.269       15.063              O        .000     CaO       4.944
H2O    14.850        5.864              N        .424     MgO       6.231
CH4     3.397        1.506              S        .485     CaS       5.415
NH3      .459         .192              Ash    10.306     Inert      .510
H2S      .108         .022              -----------       ------------
N2    188.153       47.778              Sum    35.598     Sum      17.100
Ar      3.268         .582
-----------      -------                HHV(Btu/Lb Char)=10221.
Sum 344.313      100.000                LHV(Btu/Lb Char)=10182.

HHV(Btu/Lb)=   2095.                    HHV(Btu/Lb Sorb)= 1618.
LHV(Btu/Lb)=   1954.                    (on CaCO3-MgCO3 base)
HHV(Btu/scf)=   143.
LHV(Btu/scf)=   134.                    QPFB(LHV:Btu/Lb Avg)= 7515.
               \                                       /
                \                                     /
                 \                                   /
                  \                                 /
                   \                               /
                    \                             /
                     \                           /
                      FWFWFWFWFWFWFWFWFWFWFW
               77.F   F                    W      415.F
    Purge ---------->F     CARBONIZER      W <-------- Steam
                      F                    W
         Lb/hr        F     P(psia)=294.   W            Lb/hr
 N2       .000        F     T(F)=1800.     W            16.180
                      F                    W
                      FWFWFWFWFWFWFWFWFWFWFW
                     /          |            \
                    /           |             \
                   /            |              \
                  /             |               \
          70.F/            70.F|         600.F\
              /                 |                 \
             /                  |                  \
        Coal                Sorbent                 Air

         Lb/hr                        Lb/hr                          Lb/hr
C        71.912           CaCO3    16.336              O2        57.804
H         4.690           MgCO3    13.033              N2       187.697
O         6.337           Moist      .150              Ar         3.268
N         1.258           Inert      .510              H2O        2.038
S         2.993           -------------                CO2         .000
Ash      10.306           Sum      30.029              -------------
Moist     2.500                                        Sum      250.807
-------------             Ca/S=     1.750
Sum      99.996                                        Stoi%     25.584

HHV(Btu/Lb MF)=13250.

Note: HHV & LHV - Fuel heating value as it burns out @ STD.
```

Phase 3 Dry Feed 1800EF Carbonizer Balance 2/12/1999

Figure 3

Under Round 5 of the US DOE Clean Coal Technology Program, FW has proposed construction of a Second-Generation PFB demonstration plant at Lakeland, Florida. In response to a FETC request, FW presented a paper discussing the proposed demonstration plant at the 13th US-Korea Joint Workshop on Energy and the Environment in Reno, Nevada, September 13-17, 1999.